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H01Q 7/00

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H1Q QDH

(56) Documents Cited

GB 1272990 A

EP 0829917 A1

WO 1997/001197 A1

DE 004327917 A

US 4620155 A

US 3761933 A

(58) Field of Search

UK CL (Edition V) H1Q

INT CL⁷ H01Q

Other: ONLINE: WPI, EPODOC, JAPIO

(54) Abstract Title

Loop antennae with opposed gaps

(57) An antenna comprises a single loop 10 having opposed gaps 12, 14. The antenna can be formed by etching copper on a PCB. In another embodiment (Fig. 6), two such loops are arranged orthogonally and by switching across one of the gaps (Fig. 10) the antenna can be operated selectively in horizontal linear polarisation or in circular polarisation.

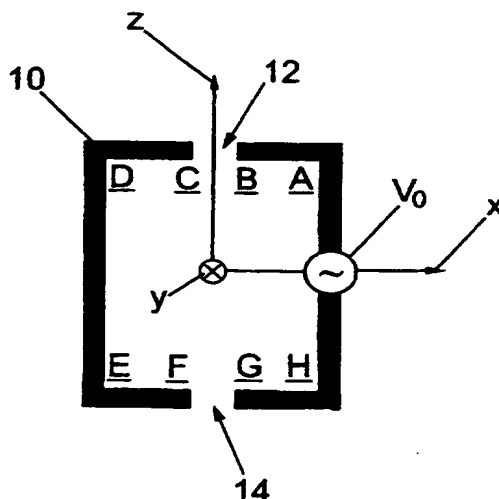


Fig. 1

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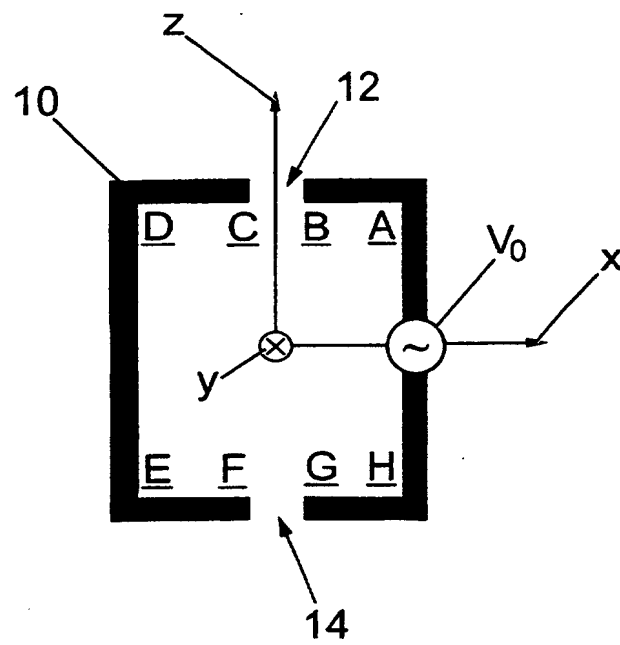
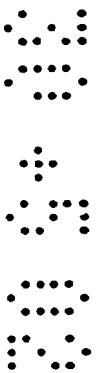


Fig. 1



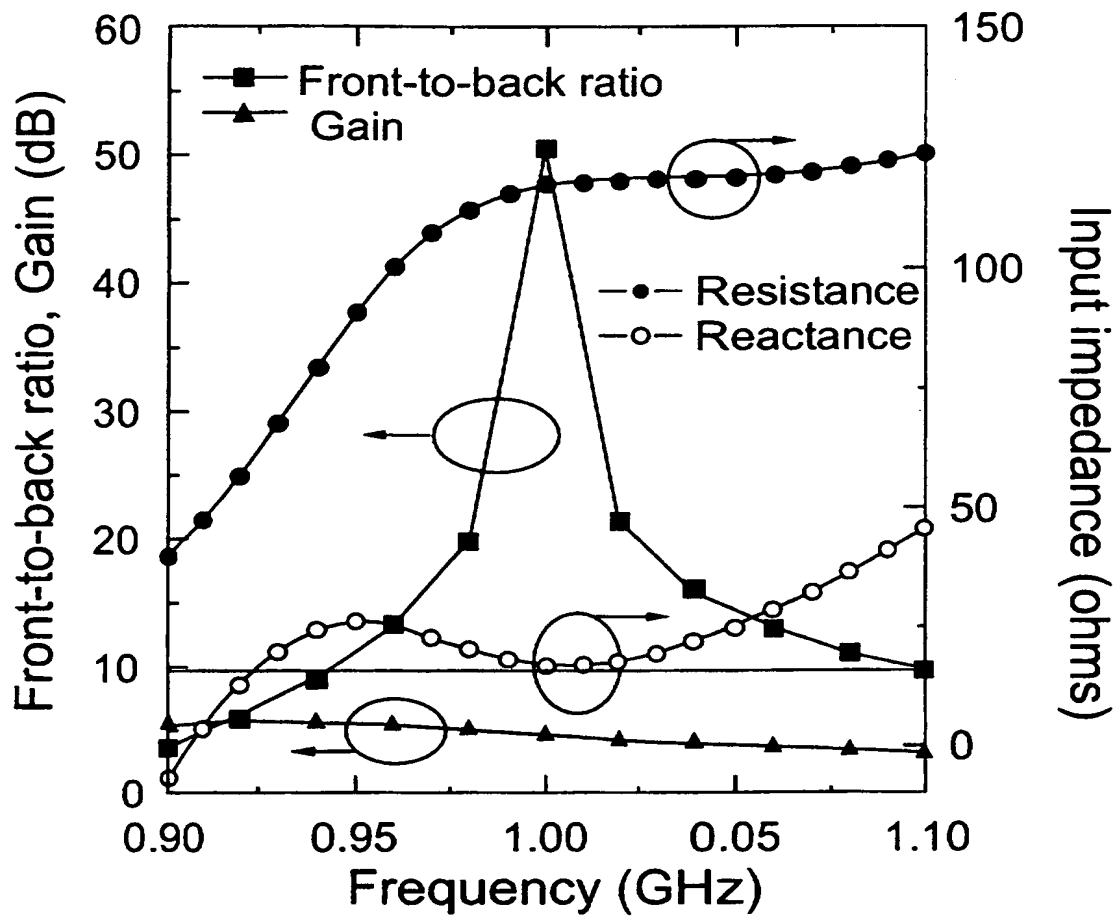


Fig. 2

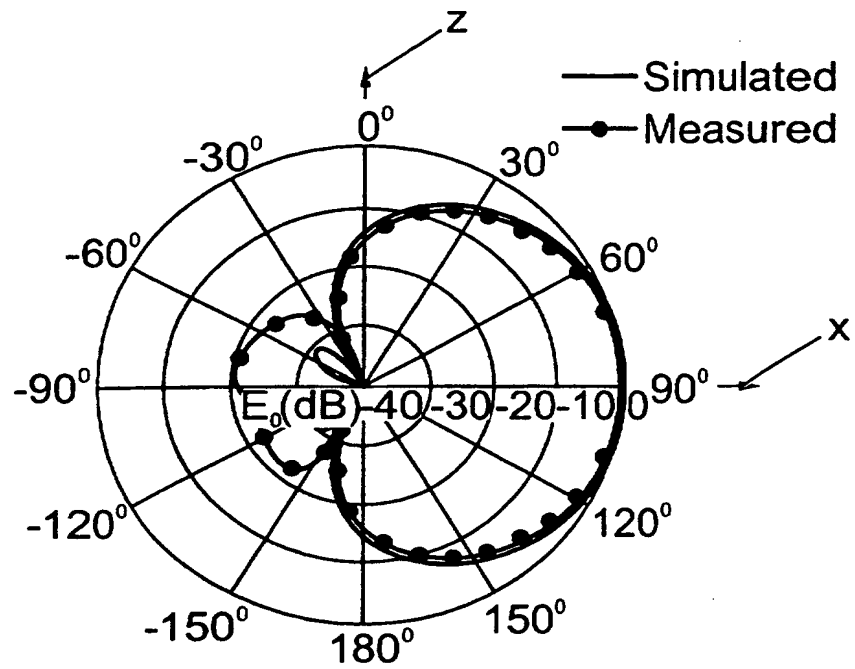


Fig. 3a

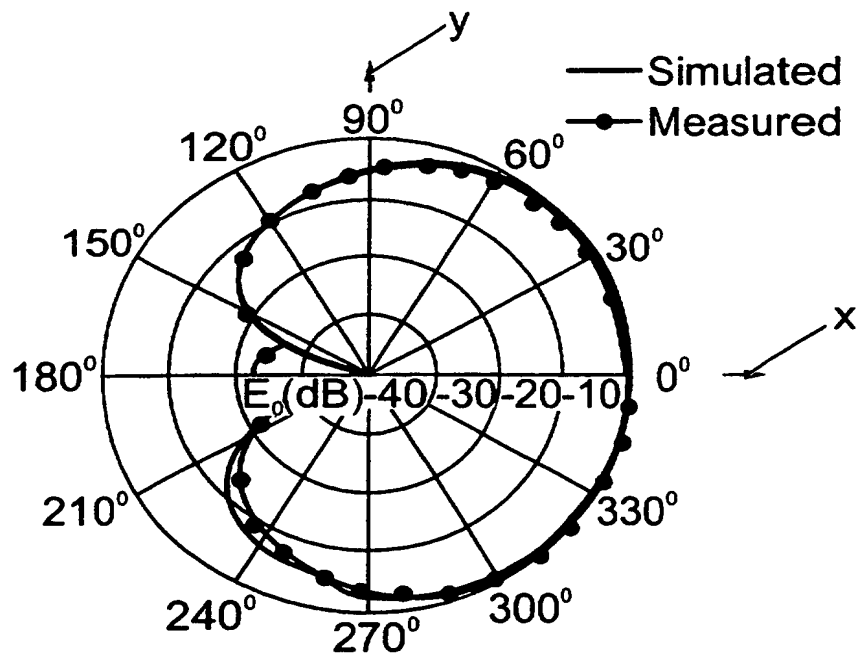
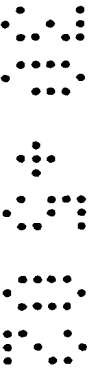


Fig. 3b



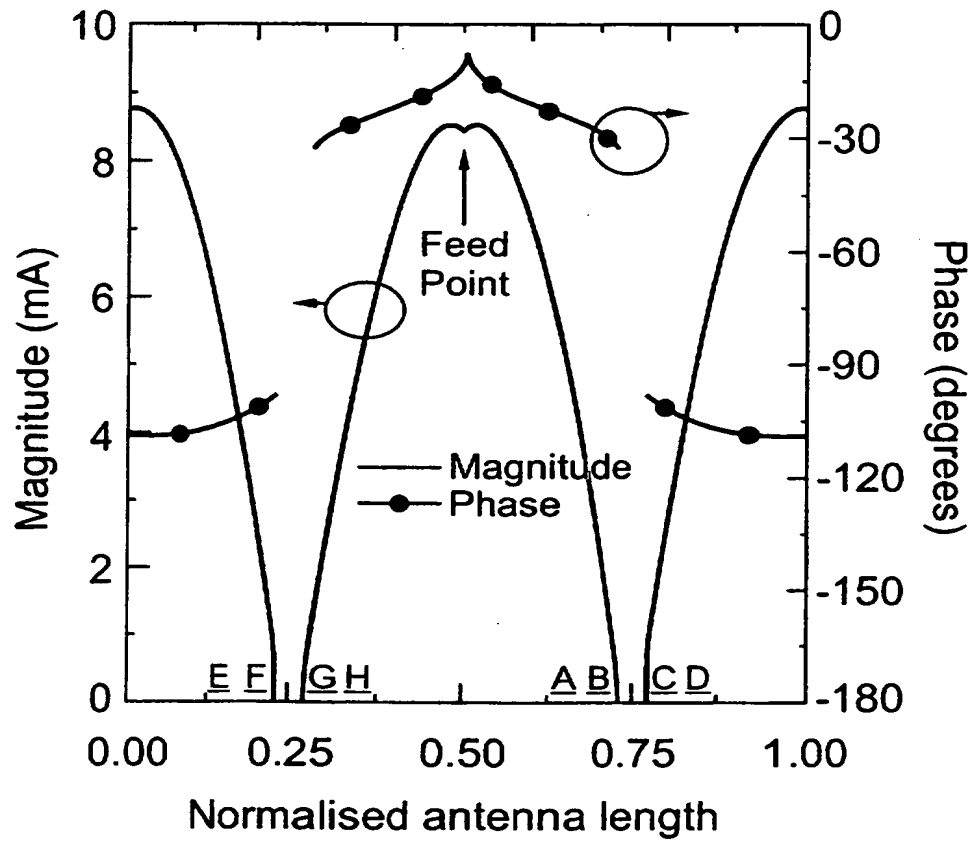
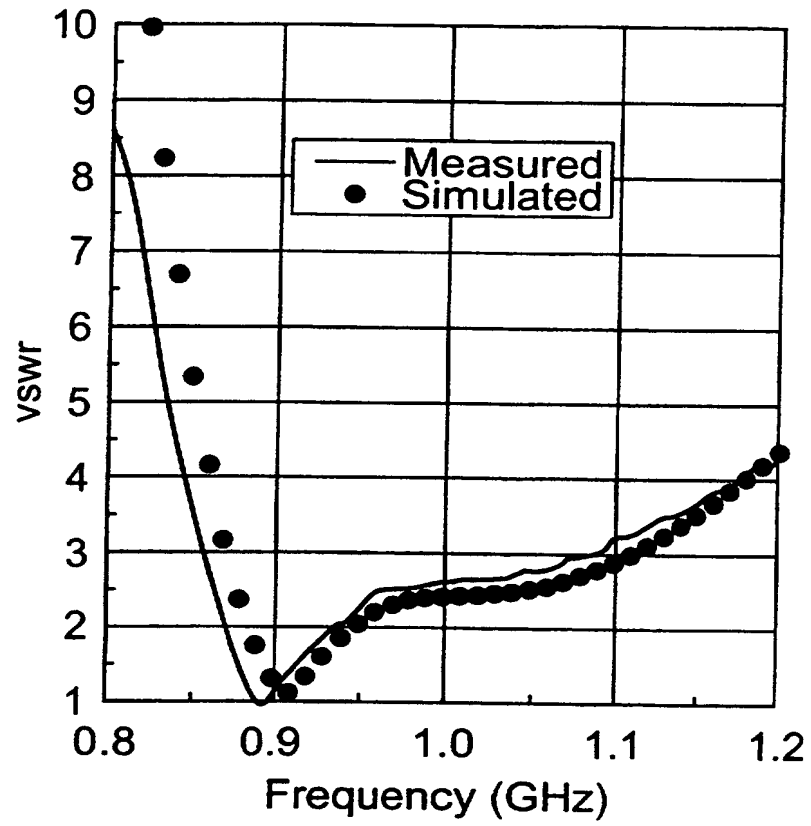


Fig. 4

*Fig. 5*

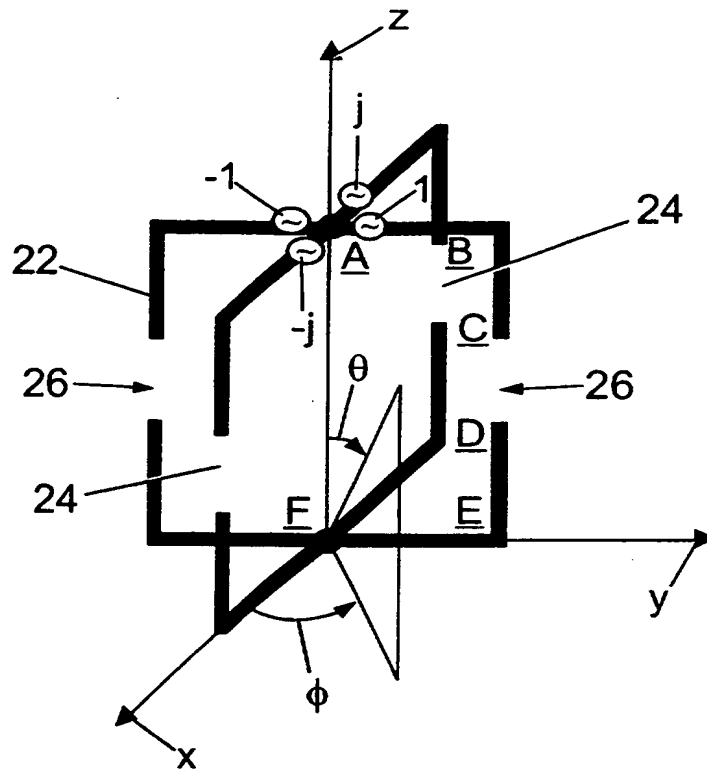
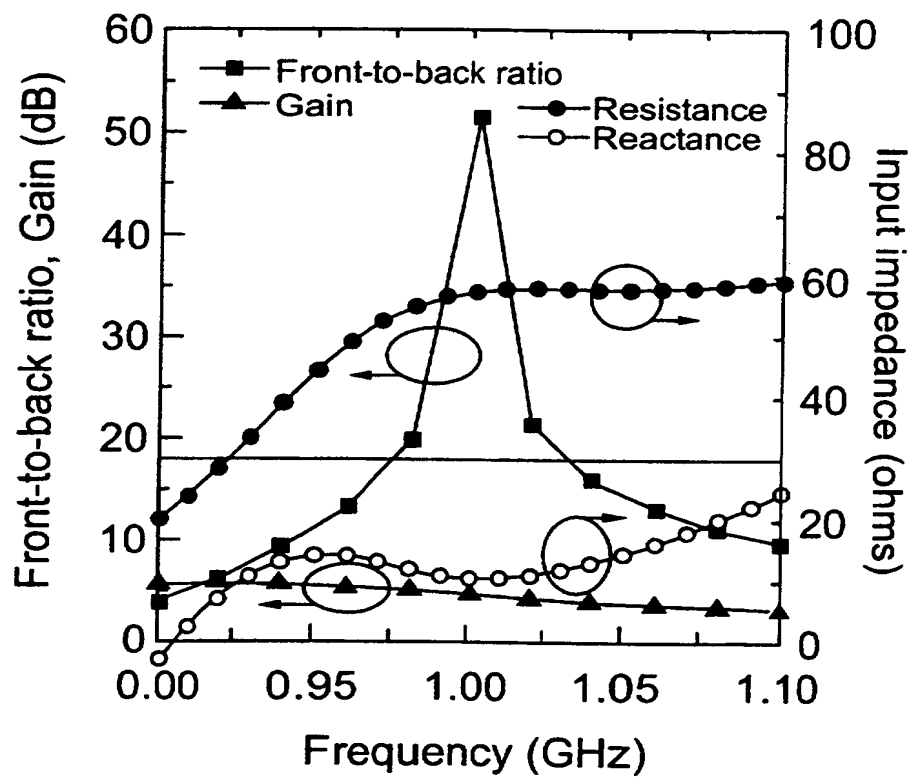


Fig. 6

*Fig. 7*

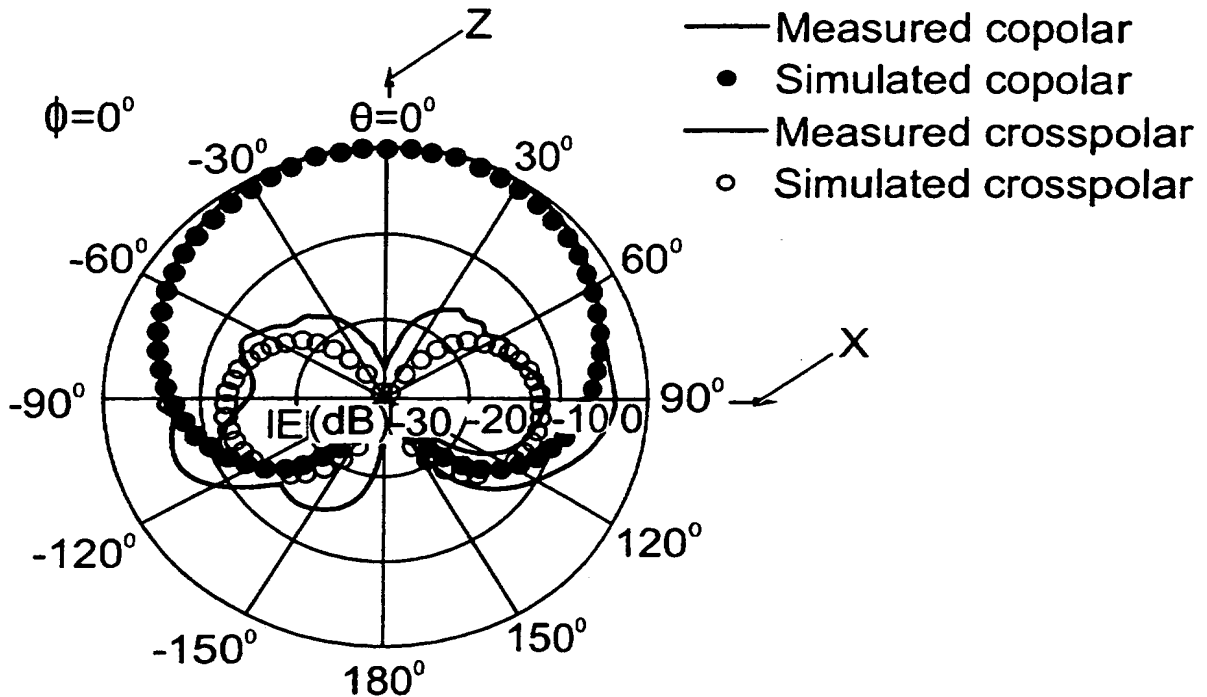


Fig. 8a

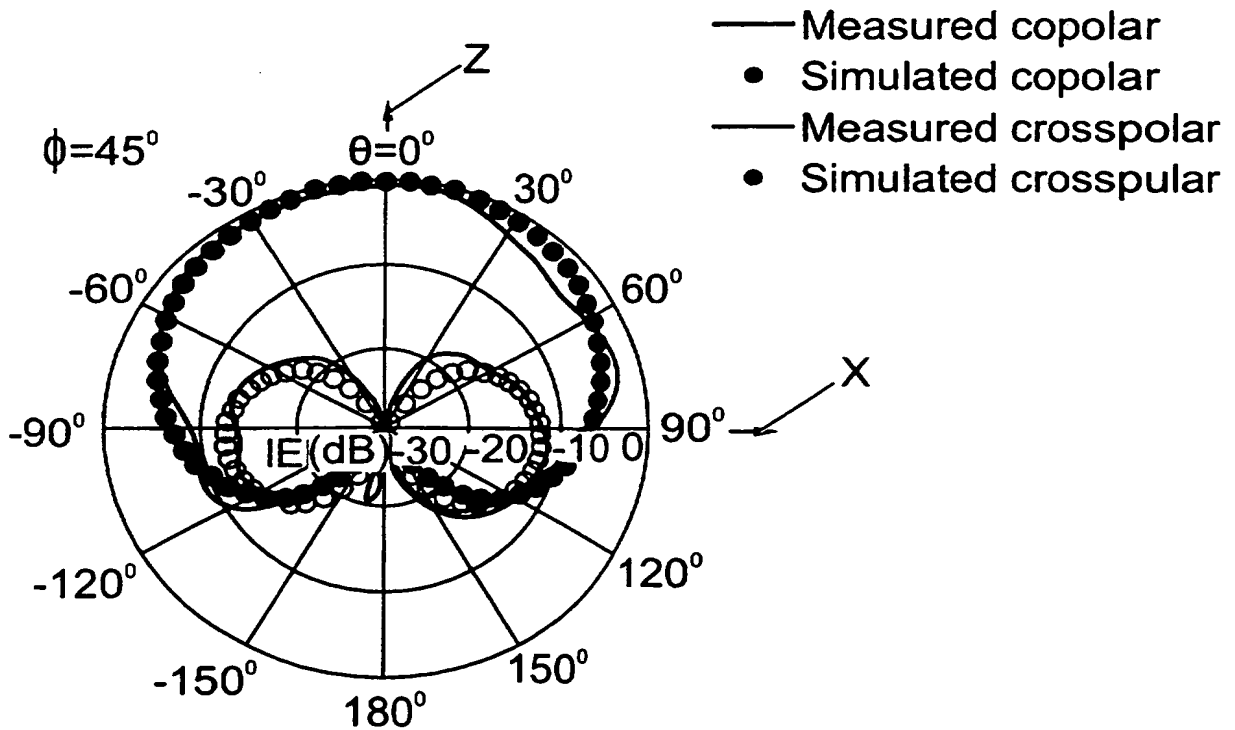
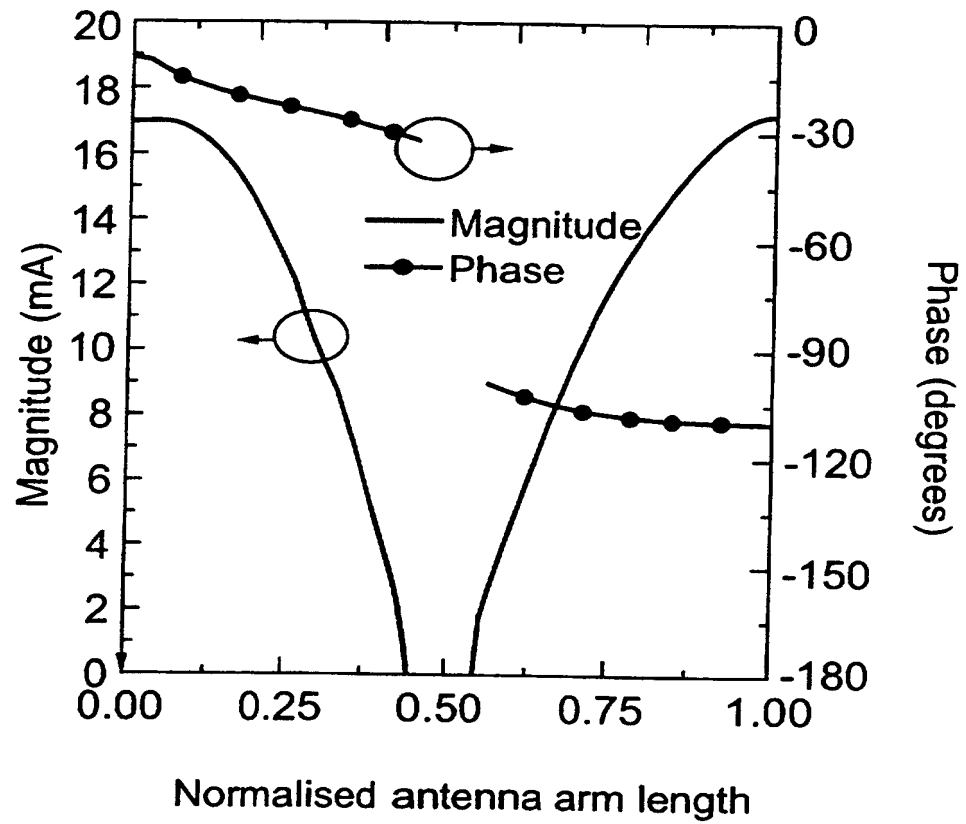
 $\phi = 0^\circ$ 

Fig. 8b

 $\phi = 45^\circ$

*Fig. 9*

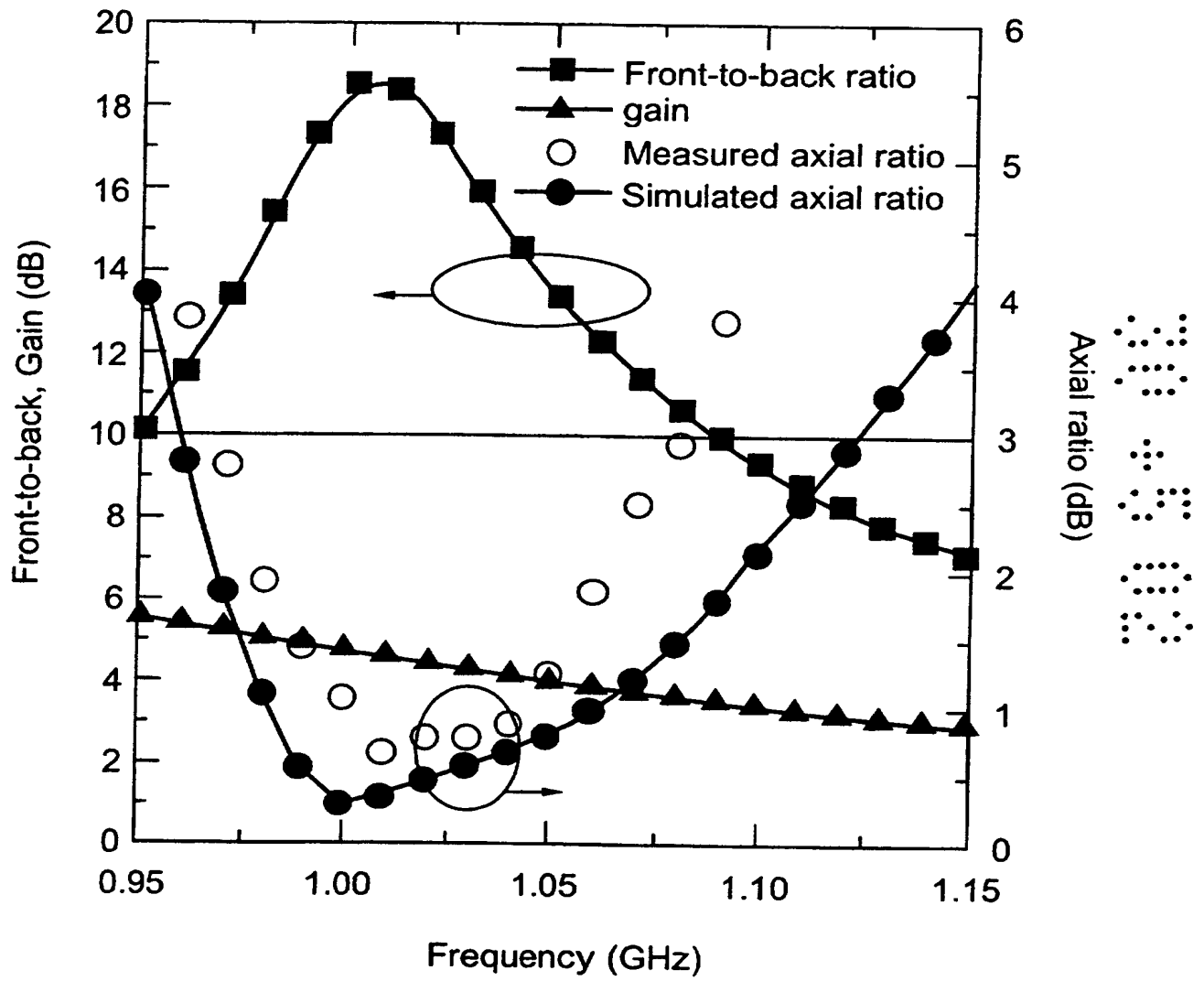


Fig. 11

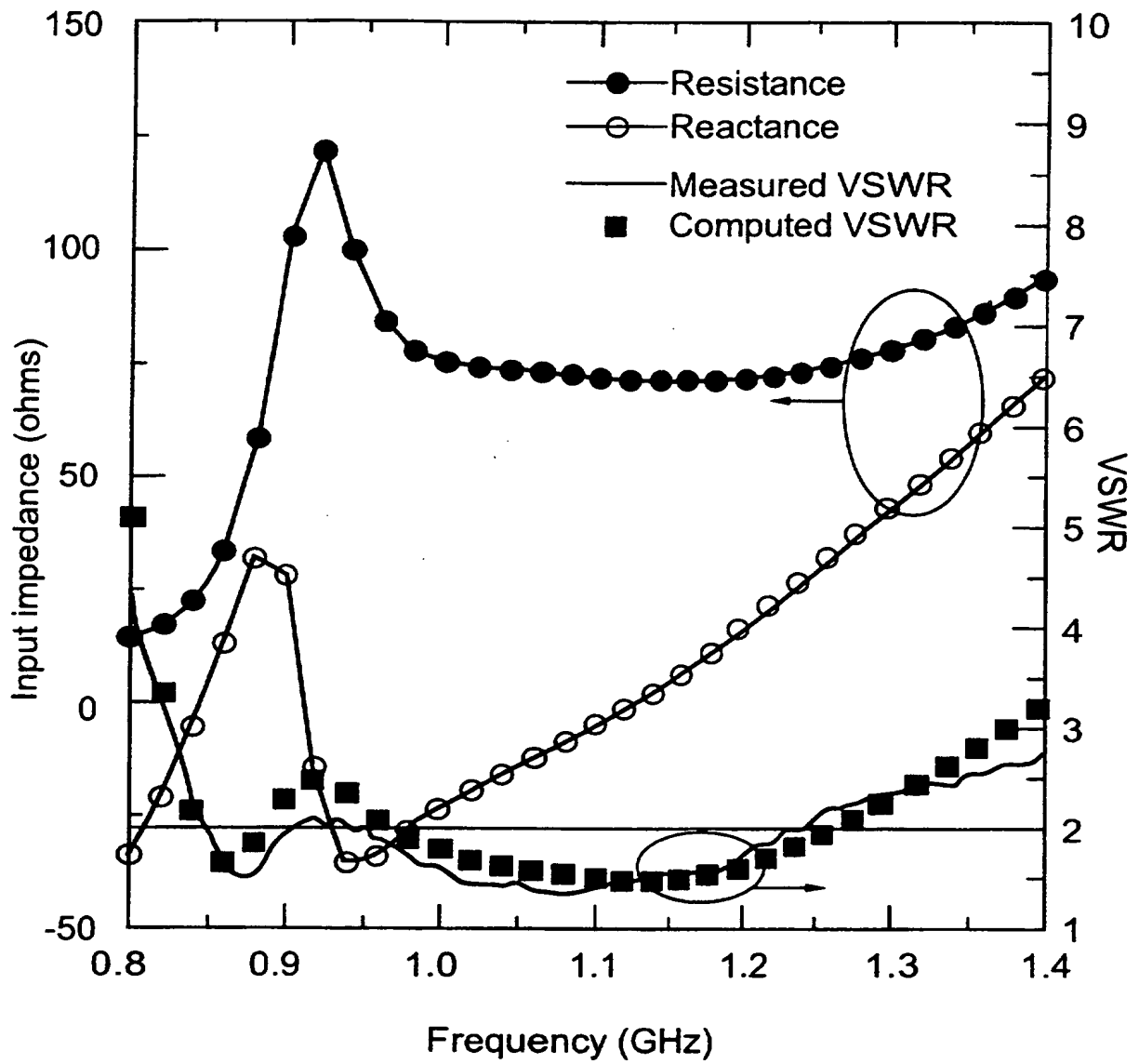


Fig. 12

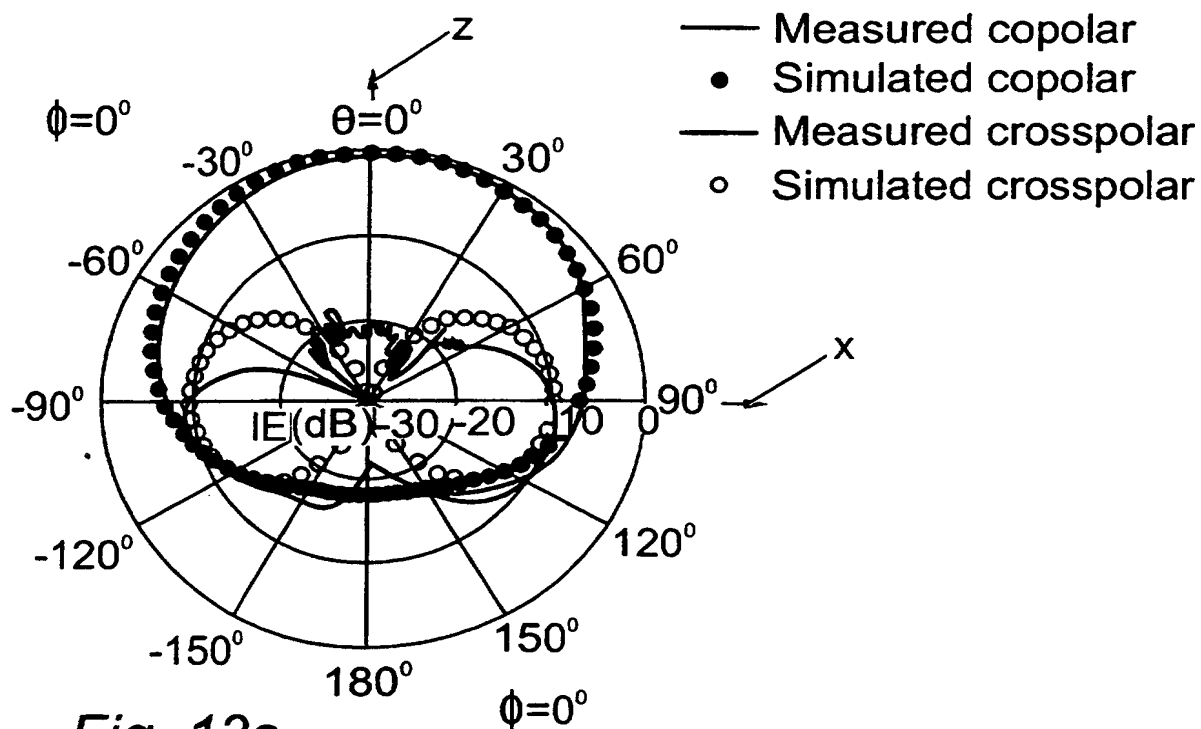


Fig. 13a

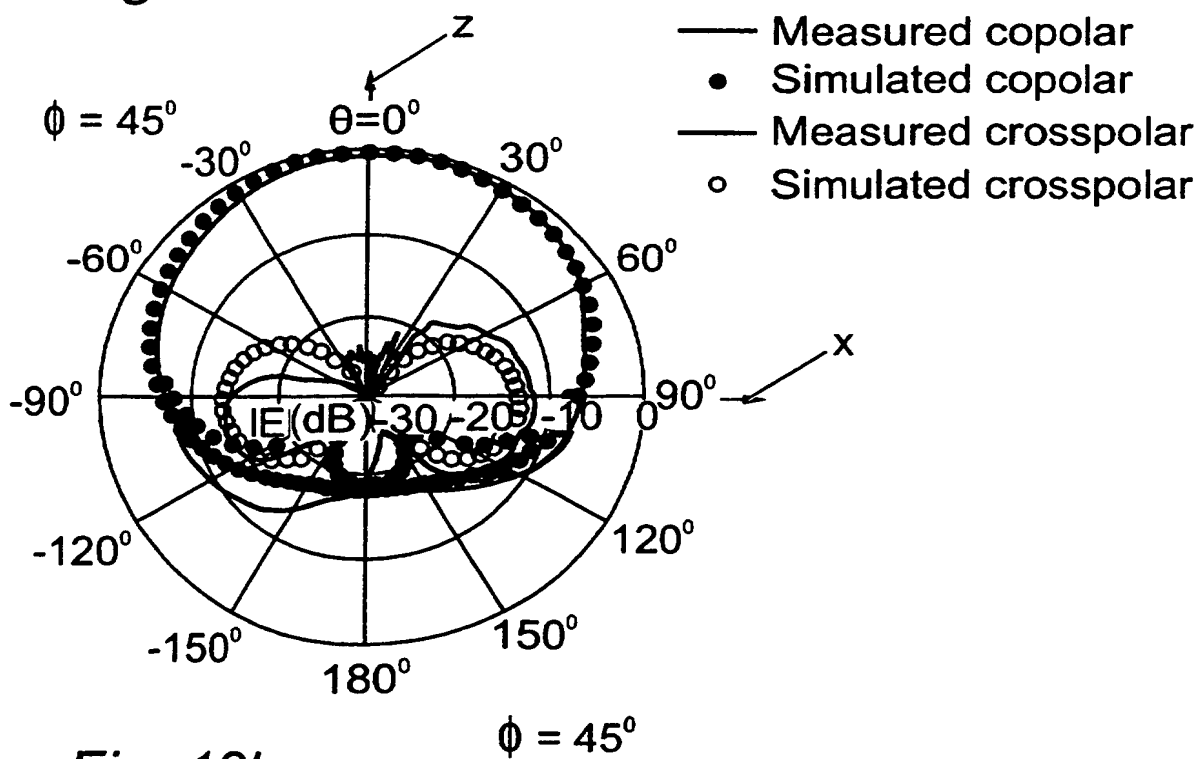


Fig. 13b

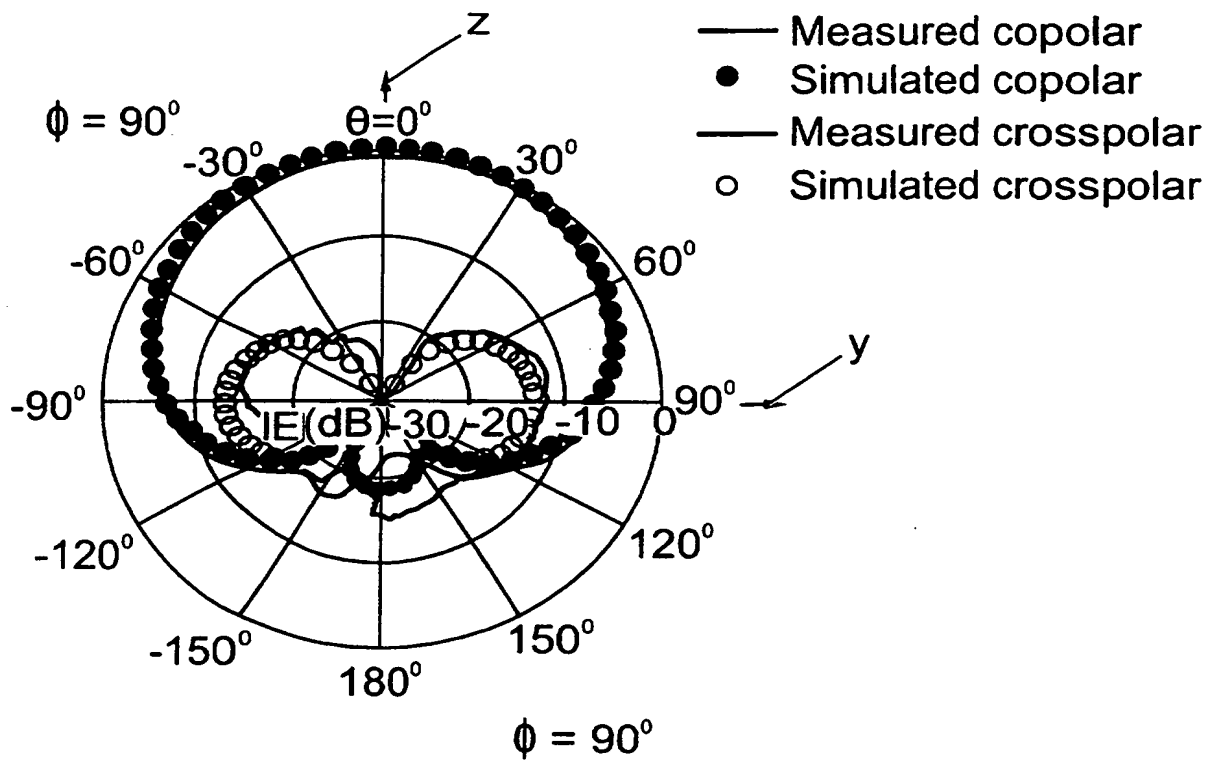


Fig. 13c

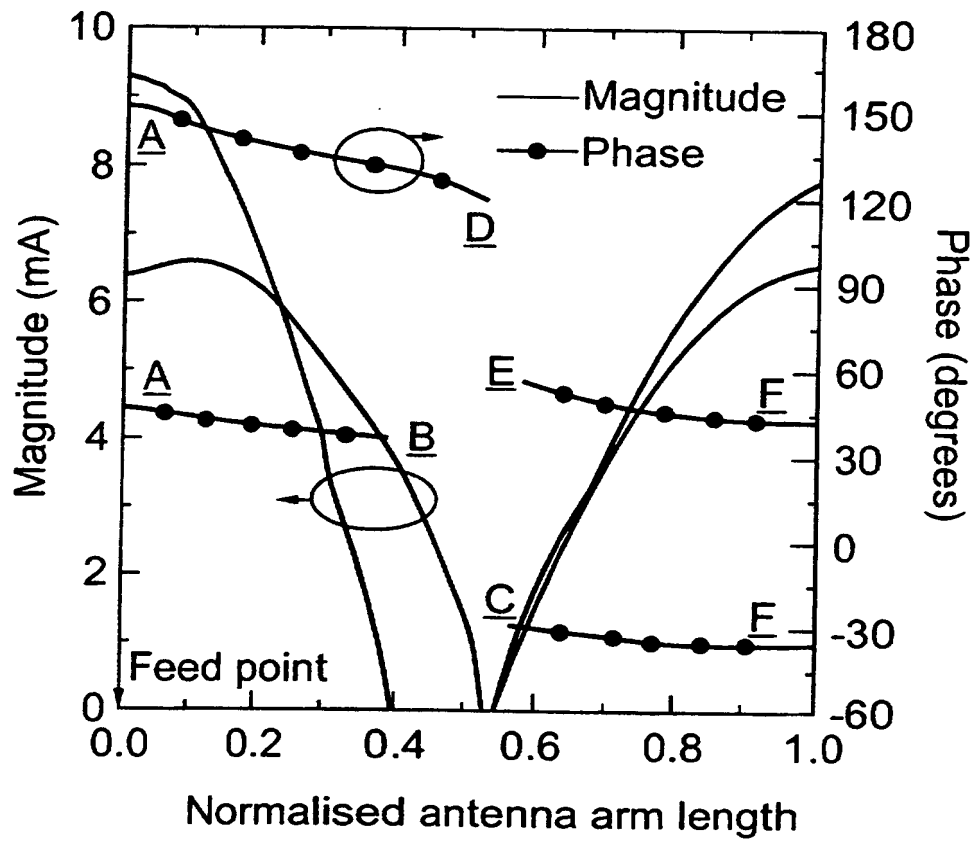


Fig. 14

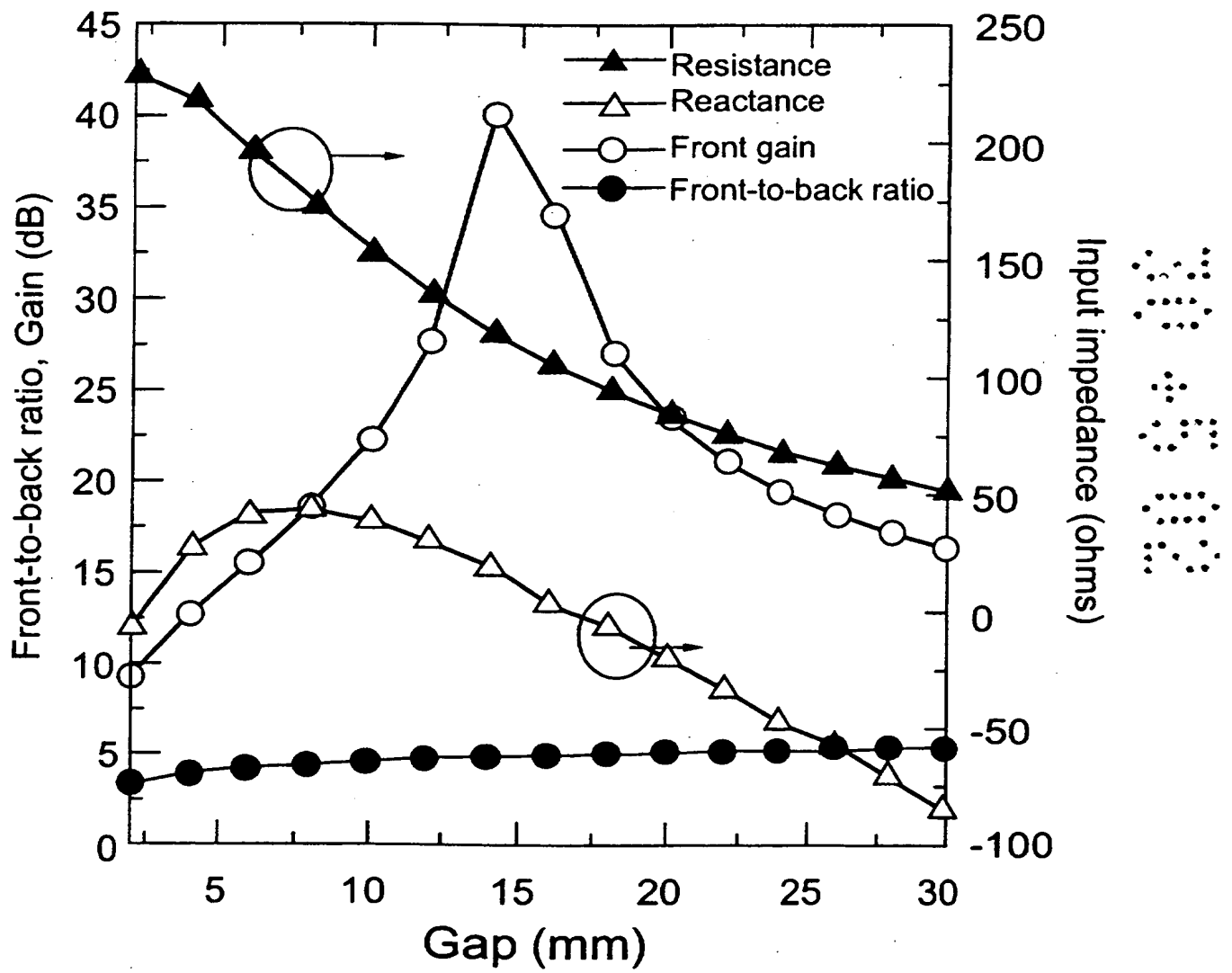


Fig. 15

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1 "Improvements relating to Antennas"

2

3 This invention relates to antennas, and more
4 particularly to antennas suitable for use in V/UHF
5 bands in mobile applications, and for use in
6 applications such as personal communications and
7 GPS.

8

9 For a receiving antenna, the primary requirement is
10 usually large signal-to-noise ratio [1]. Thus a
11 unidirectional radiation pattern with a high front-
12 to-back ratio is desirable to minimise reception of
13 interference from the back direction.

14

15 An object of the present invention is to provide
16 antennas which provide a good front-to-back ratio in
17 a manner which is simple and inexpensive to produce.

18

19 The present invention, in its widest aspect,
20 provides an antenna comprising a wire loop which is
21 interrupted by two opposed gaps.

22

1 Preferably, the wire loop is embedded in a block of
2 dielectric, or is a metallic track on a dielectric
3 substrate, most preferably formed by etching copper
4 on a PCB.

5

6 In these forms, the invention can be used to provide
7 a unidirectional loop antenna with a radiation
8 pattern which is linearly polarised with a front-to-
9 back ratio of more than 20 dB.

10

11 This may be compared with prior art such as a
12 unidirectional dipole developed by Mikuni et al. for
13 use in the VHF band [2] and a balanced directional
14 loop antenna constructed by Brennan et al. to
15 operate in the V/UHF band [3]. Both antennas were
16 electrically small and resistively loaded, and
17 therefore they had typical gain of around 13 dB
18 below that of a half-wavelength dipole, and also
19 exhibited poor input impedance characteristics.

20

21 In another form of the present invention, two
22 antennas as defined above are arranged orthogonally.
23 In this form, the antenna can provide a backfire
24 radiation pattern which is circularly polarised and
25 has a cardioid pattern, again with a front-to-back
26 ratio of more than 20 dB.

27

28 The antenna in this form operates similarly to a
29 quadrifilar helix antenna. Since quadrifilar helix
30 antennas were developed by Gerst [4] and Kilgus [5]-
31 [6] several decades ago, they have found a variety
32 of applications in ground station and space

1 communications, such as GPS receivers [7] and
2 satellite spacecraft [8].

3

4 In this form of the invention, the antenna may be
5 fed in a four-feed arrangement via a quadrature
6 circuit; alternatively, by suitable choice of gap
7 widths a one-feed arrangement may be employed.

8

9 The antenna of the present invention may be further
10 refined by providing switching means across the loop
11 gaps, whereby the gaps may be selectively open
12 circuit or short circuit. When the gaps are short
13 circuited in the orthogonally crossed arrangement,
14 the radiation pattern is switched to a horizontal
15 linearly polarised pattern. This allows a single
16 antenna to be used for receiving satellite signals
17 (circularly polarised) and terrestrial, e.g.
18 cellphone, signals (linearly polarised).

19

20 Embodiments of the invention will now be described,
21 by way of example only, with reference to the
22 drawings, in which:

23

24 Fig. 1 illustrates a unidirectional antenna
25 forming a first embodiment of the invention;

26 Fig. 2 shows predicted frequency response of
27 various parameters for the antenna of Fig. 1;

28 Figs. 3(a) and 3(b) show measured and predicted
29 radiation patterns at 1 GHz for the antenna of Fig.
30 1, in the E-plane and H-plane respectively;

31 Fig. 4 shows the current distribution along the
32 antenna of Fig. 1;

1 Fig. 5 is a comparison of measured and simulated
2 VSWR for the antenna of Fig. 1 in a 50Ω system;

3 Fig. 6 illustrates a second embodiment in the
4 form of a four-feed quadrifilar loop antenna;

5 Fig. 7 shows the frequency responses of various
6 parameters of the antenna of Fig. 6;

7 Fig. 8(a) shows the radiation pattern at 1 GHz
8 for the antenna of Fig. 6 with $\phi = 0$;

9 Fig. 8(b) shows the same pattern for $\phi = 45^\circ$;

10 Fig. 9 shows the current distribution along one
11 arm of the antenna of Fig. 6;

12 Fig. 10 illustrates a further embodiment in the
13 form of a one-feed quadrifilar loop antenna;

14 Fig. 11 shows the frequency responses of various
15 parameters of the antenna of Fig. 10;

16 Fig. 12 shows input impedance characteristics of
17 the antenna of Fig. 10;

18 Figs. 13(a), 13(b) and 13(c) show the radiation
19 patterns at 1 GHz for the antenna of Fig. 10 at,
20 respectively, $\phi = 0$, $\phi = 45^\circ$, and $\phi = 90^\circ$;

21 Fig. 14 shows the current distribution along two
22 adjacent arms of the antenna of Fig. 10; and

23 Fig. 15 shows the effect of varying the size of
24 gaps in the embodiment of Fig. 10.

25

26 Referring to Fig. 1, in a first embodiment an
27 antenna comprises a conducting loop 10 which is
28 etched in copper on a PCB. The principal dimensions
29 are given in Fig. 1 in mm. The loop 10 has a width
30 $w = 6$ mm and a thickness $t = 17.5$ μm printed on an

1 RT/Duroid dielectric substrate (thickness = 0.254mm,
2 $\epsilon_r = 2.2$).

3

4 The antenna is centre-fed by a quarter-wavelength
5 folded balun of conventional design constructed from
6 50 Ω coaxial cable.

7

8 The total length of the loop 10 is about one
9 wavelength (λ_0) and the separation between parallel
10 sides AH and DE is $\lambda_0/4$.

11

12 It is well known that a one-wavelength loop antenna
13 has a bi-directional figure-of-eight radiation
14 pattern in the H-plane (x-y plane, Fig. 1). In the
15 present invention, this is modified by introducing
16 gaps in opposite sides of the loop.

17

18 In the present embodiment, gaps 12 and 14 are
19 provided in the parallel sides AD and HE of the loop
20 10. The gaps act as capacitances and, by adjusting
21 the gap width BC or GF, back-fire operation with
22 maximum directivity in the positive x-direction can
23 be obtained.

24

25 To obtain a maximum front-to-back ratio, a design
26 optimisation was carried out based on a wire grid
27 model numerically simulated using NEC [9]. In the
28 simulation, the etched copper strip 10 of Fig. 1,
29 width w , was modelled by a circular wire with an
30 equivalent wire radius $r = w/4$. Due to the very
31 small substrate thickness and its low dielectric

1 constant, the impact of the dielectric substrate was
2 considered to be negligible.

3

4 At a gap of 14.5 mm the theoretical maximum front-
5 to-back ratio was optimised to be 50 dB. The
6 frequency response of the front-to-back ratio, gain
7 and impedance are shown in Fig. 2. It is observed
8 that the predicted 10-dB front-to-back ratio
9 bandwidth is about 15%. The theoretical maximum
10 power gain is found to vary from 5.6 dBi at 0.9 GHz
11 to 3.4 dBi at 1.1 GHz, and 4.8 dBi at 1 GHz.

12

13 The radiation patterns simulated at 1 GHz in the E-
14 plane (x-z plane) and H-plane (x-y plane) are
15 plotted in Fig. 3 together with measured results for
16 comparison. Good agreement is obtained. The small
17 difference between simulation and measurement in the
18 backward direction is probably due to the scattering
19 from the feeding structure. Experimentally we
20 observe a front-to-back ratio of more than 20 dB
21 with maximum gain of 4.5 dBi, and in all cases
22 cross-polarisation levels better than -20 dB.

23

24 From Fig. 3 it is also noted that the radiation
25 patterns in both planes exhibit a well formed
26 cardioid. The mechanism of the exhibition of the
27 cardioid pattern can be understood by checking the
28 current distribution along the antenna as seen in
29 Fig. 4. It is seen that the currents on sides AH and
30 DE have the same magnitude but with a 90° phase
31 difference induced by the presence of the capacitive
32 gaps at BC and FG. Note that the current on side DE

1 is 90° ahead of that on side AH, and that the space
 2 separation between the two sides is a quarter
 3 wavelength.

4
 5 For the H-plane pattern, therefore, the antenna can
 6 be considered to behave as an array of two dipoles
 7 with a separation $\lambda_0/4$ and phase excitation
 8 difference 90° . Hence the current phasing and
 9 spatial distribution meets the requirement for
 10 endfire operation in the positive x-direction. For
 11 the E-plane pattern, however, the contributions from
 12 sides AD and HE must be taken into account. This is
 13 the reason why, in the E-plane, the pattern has a
 14 broader beamwidth than that for a typical two-dipole
 15 array arranged for endfire.

16
 17 The input impedance of the loop antenna 10 is
 18 plotted in Fig. 2 as a function of frequency.
 19 Around 1 GHz the value of the input impedance is
 20 about $120 + j \Omega$, which corresponds to a VSWR of 1.6 in
 21 a $75\text{-}\Omega$ reference. When matched to 75Ω the system
 22 gives $\text{VSWR} < 2$ over the frequency range from 0.9 GHz
 23 to 1.1 GHz. The input VSWR measured in a $50\text{-}\Omega$
 24 reference system is compared with the simulated
 25 result in Fig. 5; here good agreement is observed.

26
 27 It should be noted that if the gaps BC and FG in
 28 Fig. 1 were short-circuited, there would be a
 29 continuous loop antenna which will exhibit a bi-
 30 directional figure-of-eight radiation pattern in the
 31 H-plane. Thus, by providing suitable switching
 32 means the antenna of Fig. 1 may be switched from one

1 form to the other; this can be used for electrical
2 beam switching, which can be exploited for sensor
3 applications such as RF direction sensing.

4
5 The embodiment of Fig. 1, in summary, provides an
6 antenna with (a) high front-to-back ratio (> 20 dB),
7 (b) moderate gain (4.5 dBi), and (c) good input
8 impedance characteristics (easily matched to $75\text{-}\Omega$
9 transmission line). The example shown is designed
10 to operate at 1 GHz, has a minimum VSWR of 1.01 at
11 900 MHz, and exhibits a VSWR of less than 3 over the
12 frequency range 850 MHz to 1090 MHz. Such an antenna
13 can find applications in mobile communications
14 systems where simplified feed arrangements are
15 required.

16
17 In a modification (not shown), the antenna of Fig. 1
18 can be provided in the form of a wire loop, for
19 example a single copper track, embedded in a block
20 of dielectric and having opposed gaps. Effective
21 dimensions equal to Fig. 1 may be used, for example.
22 In this form, the antenna can be provided as a
23 monoblock construction similar to those used by
24 radio part manufacturers for filter parts.

25
26 Turning to Fig. 6, there is shown in schematic
27 isometric view a four-feed quadrifilar loop antenna.
28 The antenna comprises a first loop 20 and a second
29 loop 22 having the dimensions shown in mm. Each
30 loop 20, 22 is formed by etching copper strips on an
31 RT/Duroid 5880 dielectric substrate as in the
32 embodiment of Fig. 1. The strip width is 6mm.

1 Capacitive gaps 24 and 26 are provided as shown in
2 each of the vertical legs to facilitate phasing for
3 production of a cardioid shape.

4
5 The antenna of Fig. 6 was numerically simulated
6 using NEC [9]. The calculated front-to-back ratio,
7 directivity gain, and input impedance at each feed
8 point over a range of frequencies are shown in Fig.
9 7. The maximum front-to-back ratio is about 50 dB
10 at 1 GHz, and the 10-dB front-to-back ratio
11 bandwidth is about 15%. The theoretical directivity
12 in the maximum direction (z-direction) is found to
13 vary from 5.6 dB at 0.9 GHz to 3.4 dB at 1.1 GHz.
14 The input impedance has a resistance of 60Ω and a
15 reactance of 10 around 1 GHz, which is easy to match
16 to a $50\text{-}\Omega$ transmission line.

17

18 The simulated and measured radiation patterns in $\phi=0$
19 and $\phi=45^\circ$ planes are plotted in Fig. 8. The
20 measured front-to-back ratio for the co-polarisation
21 is better than 20 dB. Minimal scattering was
22 observed from the feeding structure, which consists
23 of a quadrature hybrid and two quarter-wavelength
24 folded baluns.

25

26 The backfire property of the quadrifilar loop
27 antenna can be understood by viewing the current
28 distribution along each arm of the antenna, Fig. 9.
29 It is seen that the currents on sides AB and FE have
30 the same magnitude and a phase difference of nearly
31 90° . Note that the current on side FE has a phase
32 lead of 90° with respect to that on side AB, and

1 that the separation between the two sides is a
2 quarter wavelength. Therefore, sides AB and FE
3 establish the condition necessary for radiation of a
4 cardioid shaped pattern with a maximum in the z-
5 direction. All four arms fed in phase quadrature
6 produce a cardioid shaped, circularly polarised
7 pattern.

8
9 The quadrifilar loop antenna can also radiate a
10 cardioid shaped, circularly polarised pattern
11 without using any external circuit such as the
12 hybrid component. The condition to excite the
13 circular polarised waves can be established by a
14 balun and the self-phasing of two orthogonal
15 rectangular wire loops with different gap width.

16
17 Referring to Fig. 10, the construction of the
18 antenna itself is similar to that of Fig. 6 except
19 that the gaps 24 in the loop 20 are relatively wide
20 and the gaps 26 in the other loop 22 are relatively
21 smaller.

22
23 Two adjacent arms of the quadrifilar loop are
24 connected to one half of the balanced output of the
25 balun, while the other two adjacent arms are
26 connected to the other half of the balun, the
27 connecting points being indicated at 27. The
28 desired 90° phase difference is obtained by
29 selecting the gaps such that the wider gaps 24 are
30 capacitive, while the smaller gaps 26 are inductive.
31 This technique is similar to that applied in a

1 single-fed crossed-dipole antenna for circular
2 polarisation [10].

3

4 The calculated front-to-back ratio and gain are
5 shown in Fig. 11 which indicates approximately a 10-
6 dB front-to-back ratio bandwidth of 12% and an
7 average gain of 5dB over the bandwidth. The
8 frequency dependence of axial ratio is also
9 presented in Fig. 11. The measured maximum axial
10 ratio was found to be about 0.7 dB and the axial
11 ratio bandwidth of less than 3 dB is approximately
12 10%.

13

14 Fig. 11 also shows the input impedance
15 characteristics. It can be seen that the input VSWR
16 is less than 2 over the 3-dB axial ratio and over
17 the 10-dB front-to-back ratio bandwidth. The
18 measured and calculated radiation patterns at 1GHz
19 are plotted in Fig. 12, which shows better than 18
20 dB front-to-back ratio and a half-power beamwidth of
21 approximately 120°.

22

23 The current distribution along two adjacent arms of
24 the one-feed quadrifilar loop antenna is shown in
25 Fig. 14. It is observed that the phase difference
26 between adjacent arms, say AD and AB, is indeed
27 about 90° which is the necessary condition to
28 produce circular polarisation. In addition, we note
29 that the phase difference between the upper and
30 lower sides (e.g. AB and CF) of each arm appears in
31 order of 90°, an important condition for a cardioid
32 shaped pattern.

1

2 Fig. 15 shows the effect of varying the smaller
3 gaps, while maintaining the wider gaps at 31 mm.

4

5 Thus, the embodiments of Figs. 6 and 10 provide new
6 quadrifilar antennas having similar properties to
7 quadrifilar helix antennas in producing circularly
8 polarised backfire patterns, but with structures
9 which are much easier to produce.

10

11 Both Fig. 6 and Fig. 10 can be modified by providing
12 switching means, such as transistors, selectively
13 operable to short circuit the gaps, as shown
14 schematically at 28 in Fig. 10. When the gaps are
15 open circuit, the antenna behaves as described
16 above. When the switching means are operated to
17 short circuit the gaps, the antenna has a radiation
18 pattern which is omnidirectional and linearly
19 polarised in the x-y plane.

20

21 Modifications and improvements may be made to the
22 foregoing embodiments within the scope of the
23 present invention.

24

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CLAIMS

1. An antenna comprising a wire loop which is interrupted by two opposed gaps.
2. An antenna according to claim 1, in which the wire loop is embedded within a block of dielectric.
3. An antenna according to claim 1, in which the wire loop is a metallic track on a dielectric substrate.
4. An antenna according to claim 3, in which the metallic track is formed by etching copper on a PCB.
5. An antenna according to claim 3 or claim 4, which forms a unidirectional loop antenna with a radiation pattern which is linearly polarised with a front-to-back ratio of more than 20 dB.
6. An antenna comprising two antennas as claimed in any preceding claim arranged orthogonally.
7. An antenna according to claim 6, which provides a backfire radiation pattern which is circularly polarised and has a cardioid pattern, with a front-to-back ratio of more than 20 dB.

- 1 8. An antenna according to claim 6 or claim 7,
2 the antenna being fed in a four-feed
3 arrangement via a quadrature circuit,
4
- 5 9. An antenna according to claim 6 or claim 7, the
6 antenna having a one-feed arrangement and gap
7 widths dimensioned such that the gaps in one
8 loop are capacitive and the gaps in the other
9 loop are inductive.
10
- 11 10. An antenna according to any preceding claim,
12 including switching means connected across at
13 least one of the loop gaps, whereby the gap or
14 gaps may be selectively open circuit or short
15 circuit.
16
- 17 11. An antenna according to any of claims 6 to 9,
18 including switching means connected across the
19 loop gaps, the switching means being
20 selectively operable to short circuit the gaps
21 to provide a horizontal linearly polarised
22 radiation pattern, and to open circuit the gaps
23 to provide a circularly polarised radiation
24 pattern.
25
26



INVESTOR IN PEOPLE

Application No: GB 0211460.1
Claims searched: 1 to 11

Examiner: Peter Easterfield
Date of search: 23 January 2003

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
X	1,3,4	EP 0829917 A1	(MITSUBISHI)
X	1	GB 1272990 A	(SONY)
X	1	DE 4327917 A	(MEISSNER)
X	1	US 4620155 A	(EDELSTEIN)
X	1	US 3761933 A	(SMALSER)
X	1	WO 97/01197 A1	(MOTOROLA)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^v:

H1Q

Worldwide search of patent documents classified in the following areas of the IPC⁷:

H01Q

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